Intrepid Astrophysics & Cosmology Simulations

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LANS Informal Seminar
Argonne National Lab
June 23, 2010

Topics to Discuss

- Introduction to cosmology

- The mystery of dark energy

- Pursuing answers via high performance

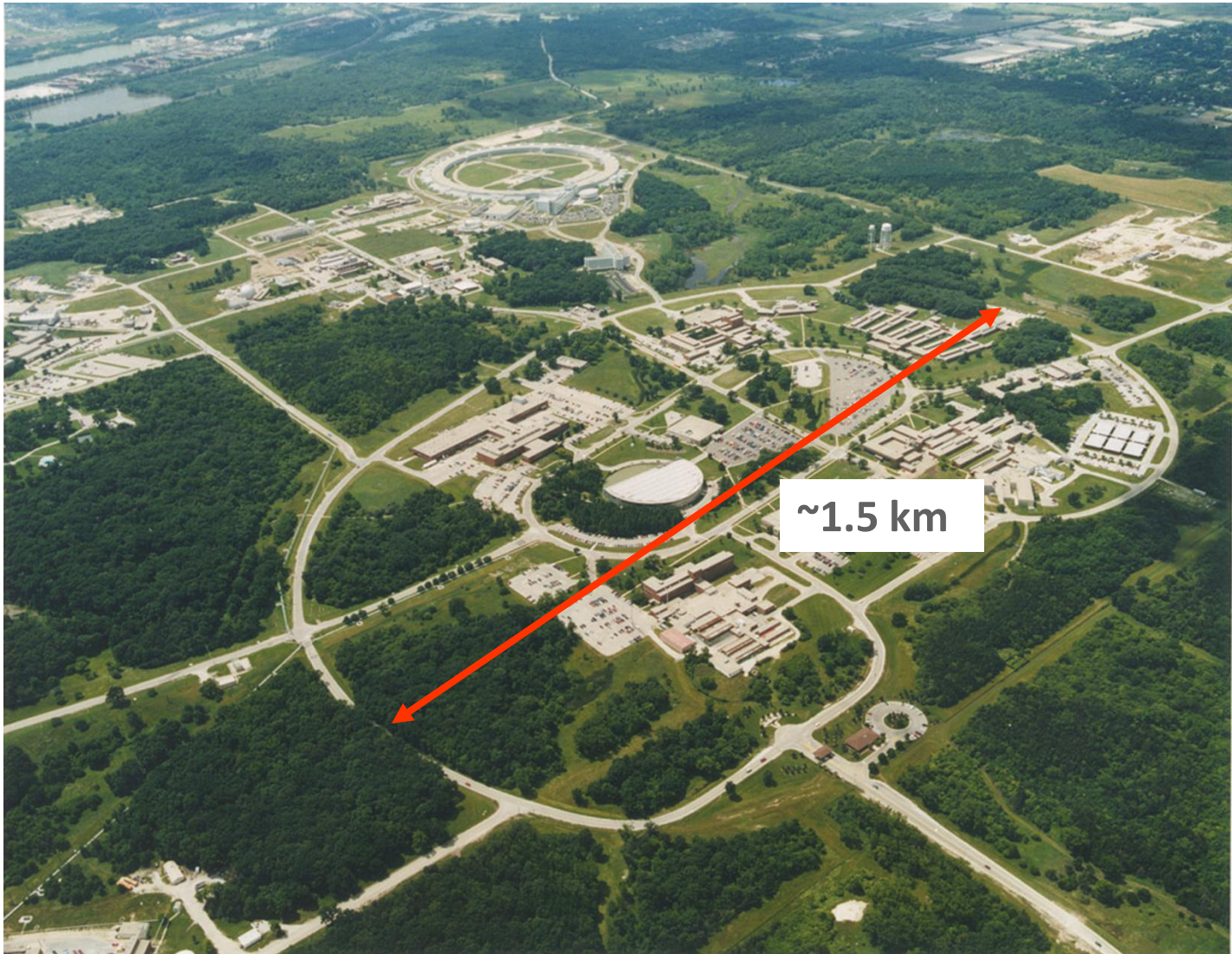 computing simulations

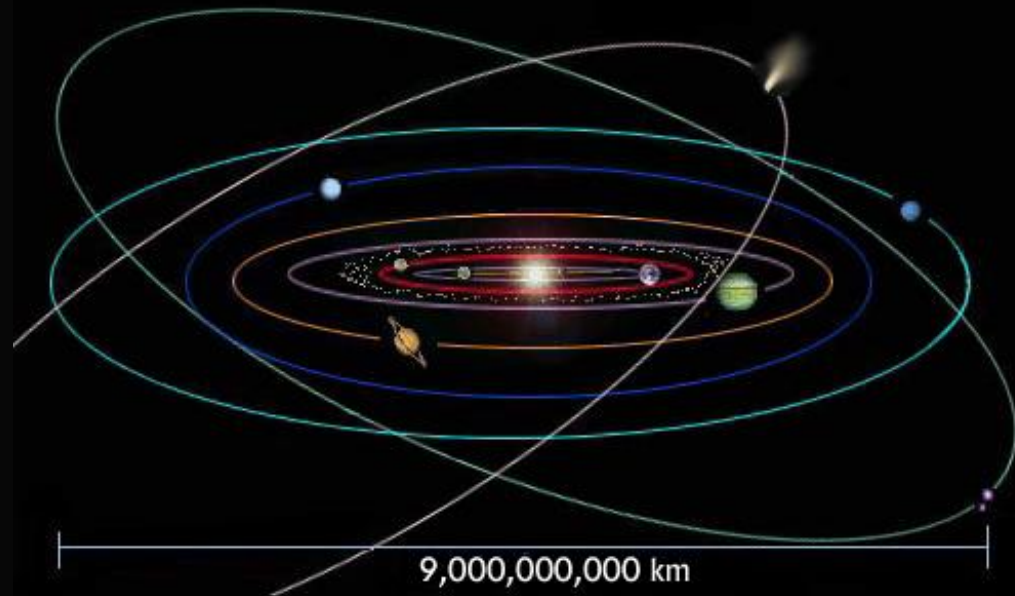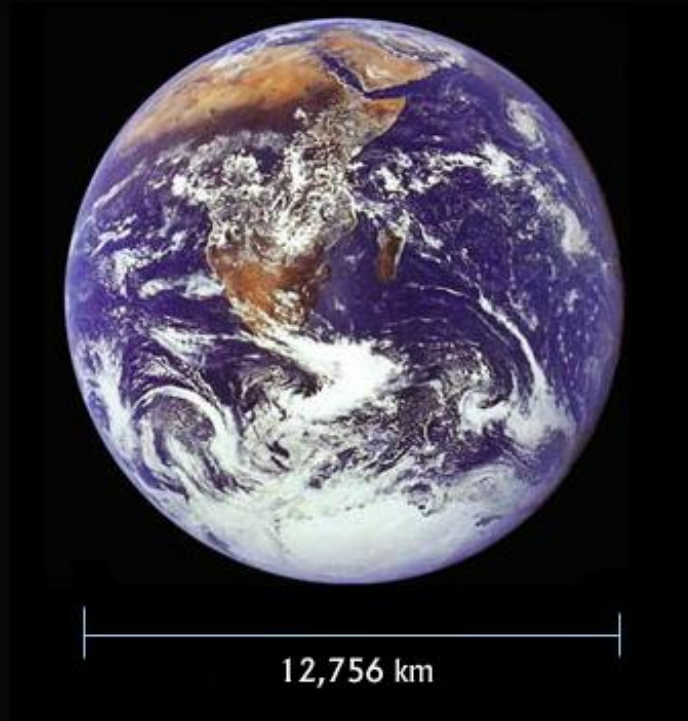- Summary & conclusions
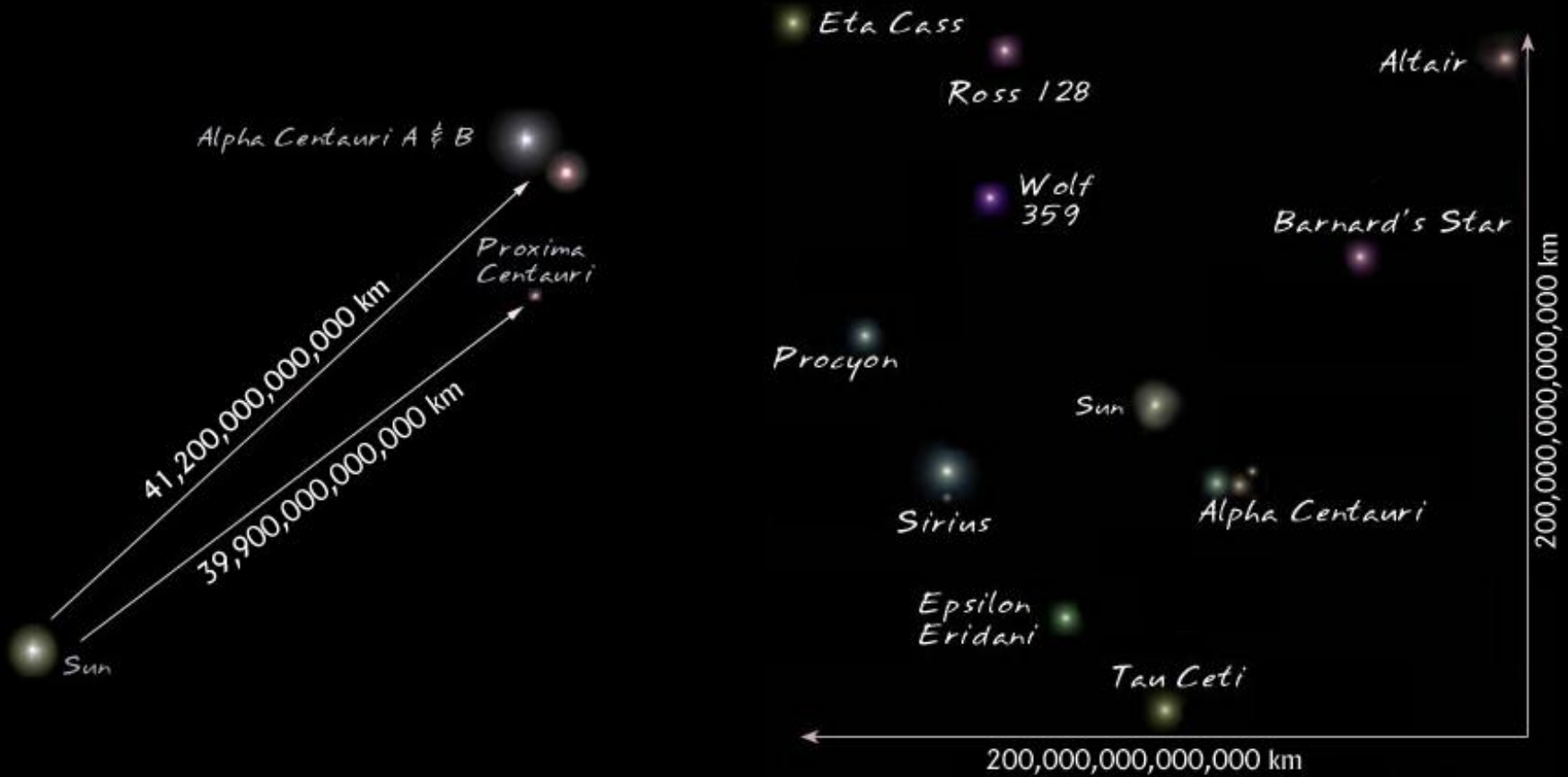
University of Chicago

Size of the Universe Image courtesy http://www.mcs.anl.gov

~1.5 km

Size of the Universe

Credit: http://heasarc.gsfc.nasa.gov/docs/cosmic/

Size of the Universe

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Size of the Universe

Milky Way

Canis Major Dwarf
397,000,000,000,000,000 km

Sagittarius
Dwarf Eliptical
738,000,000,000,000,000 km

Large Magellanic Cloud
1,693,000,000,000,000,000 km

1,980,000,000,000,000,000 km

Small Magellanic Cloud

925,000,000,000,000,000 km

Credit: http://heasarc.gsfc.nasa.gov/docs/cosmic/

Size of the Universe

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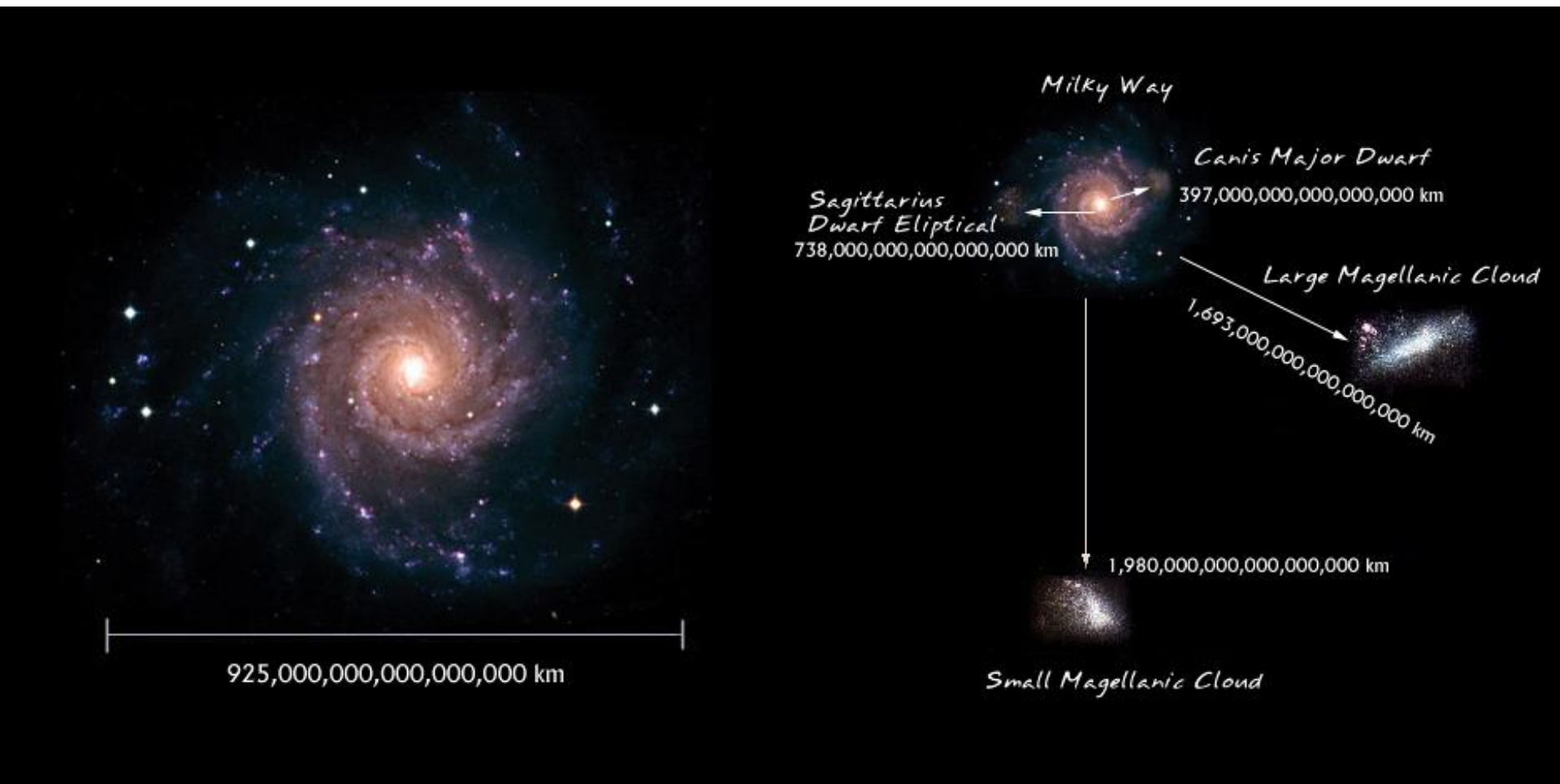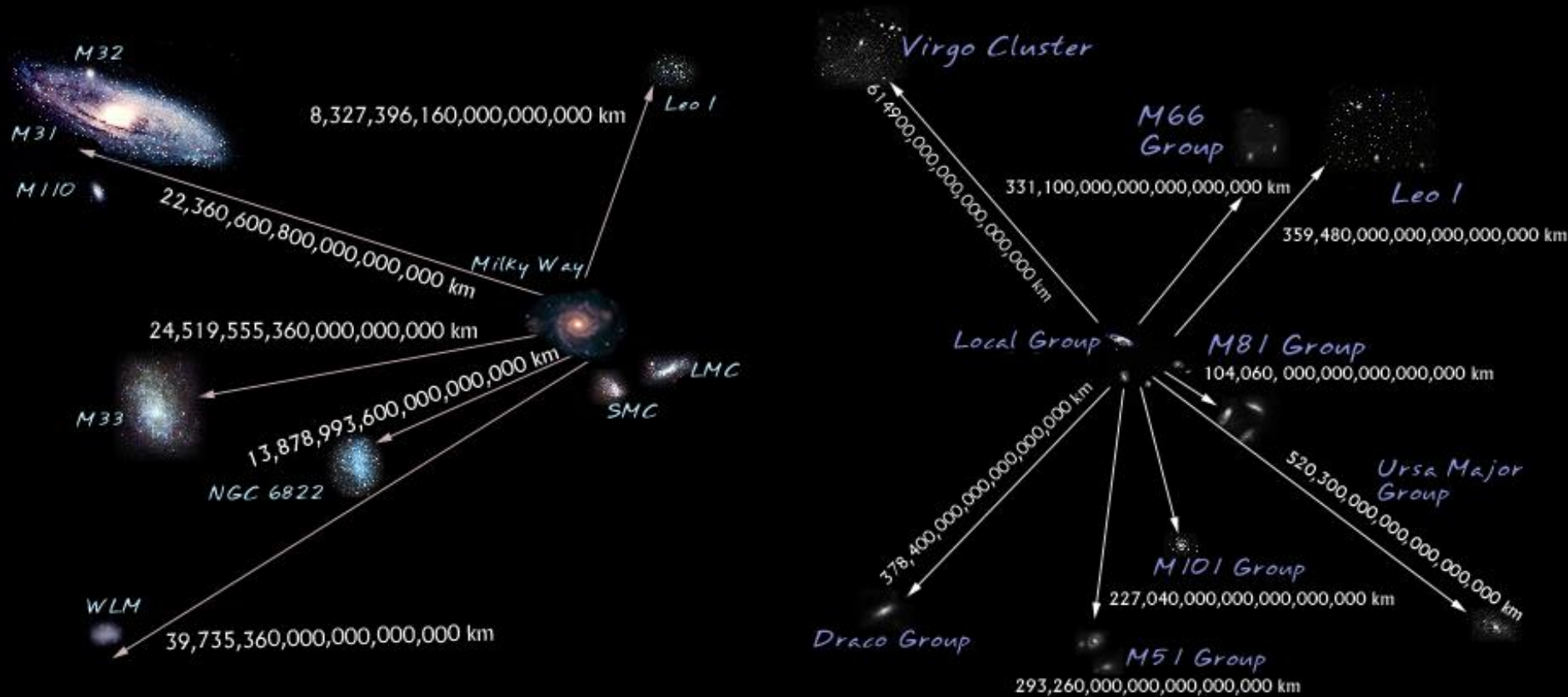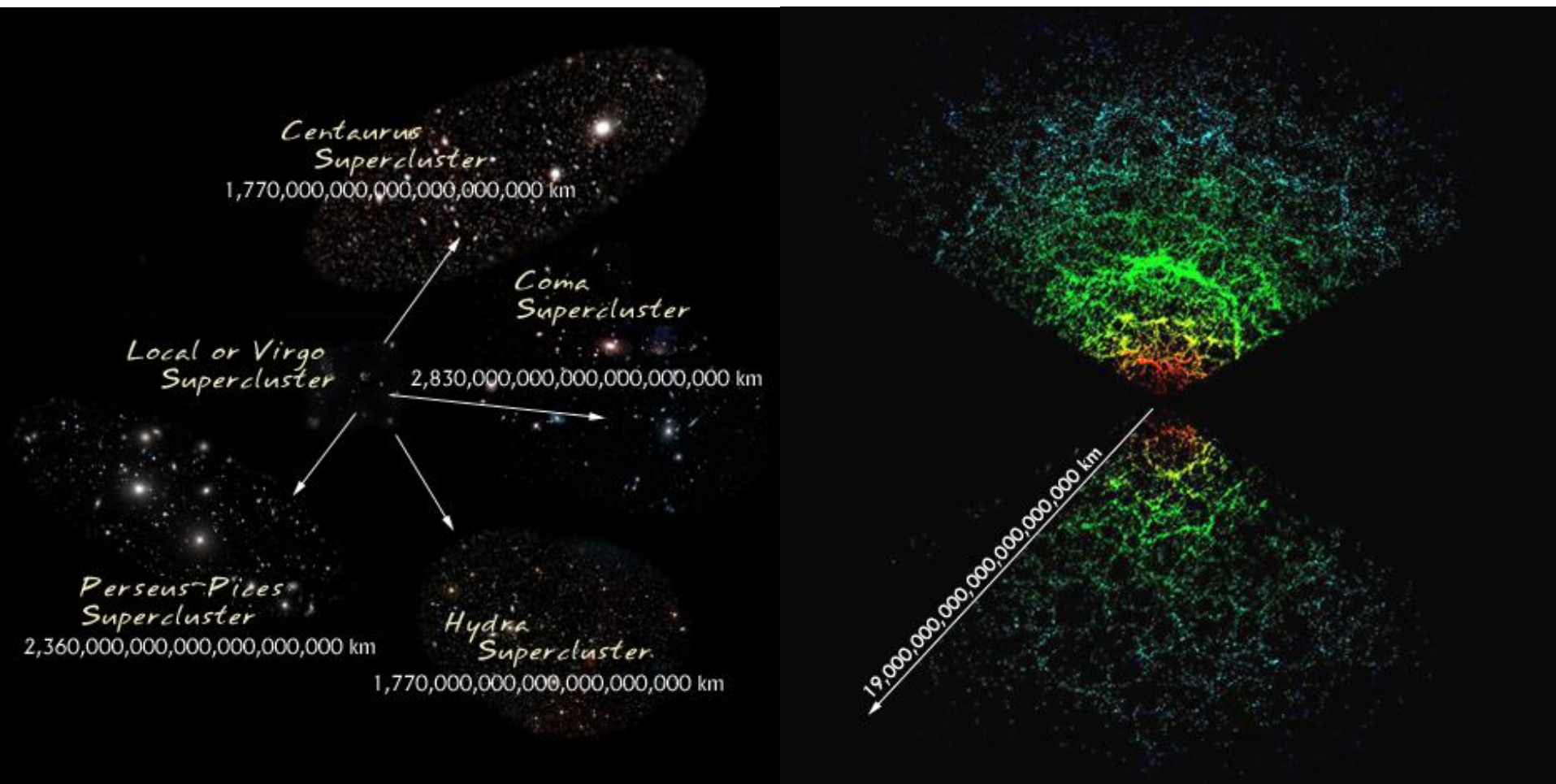
Expansion of the Universe

NASA/WMAP Science Team
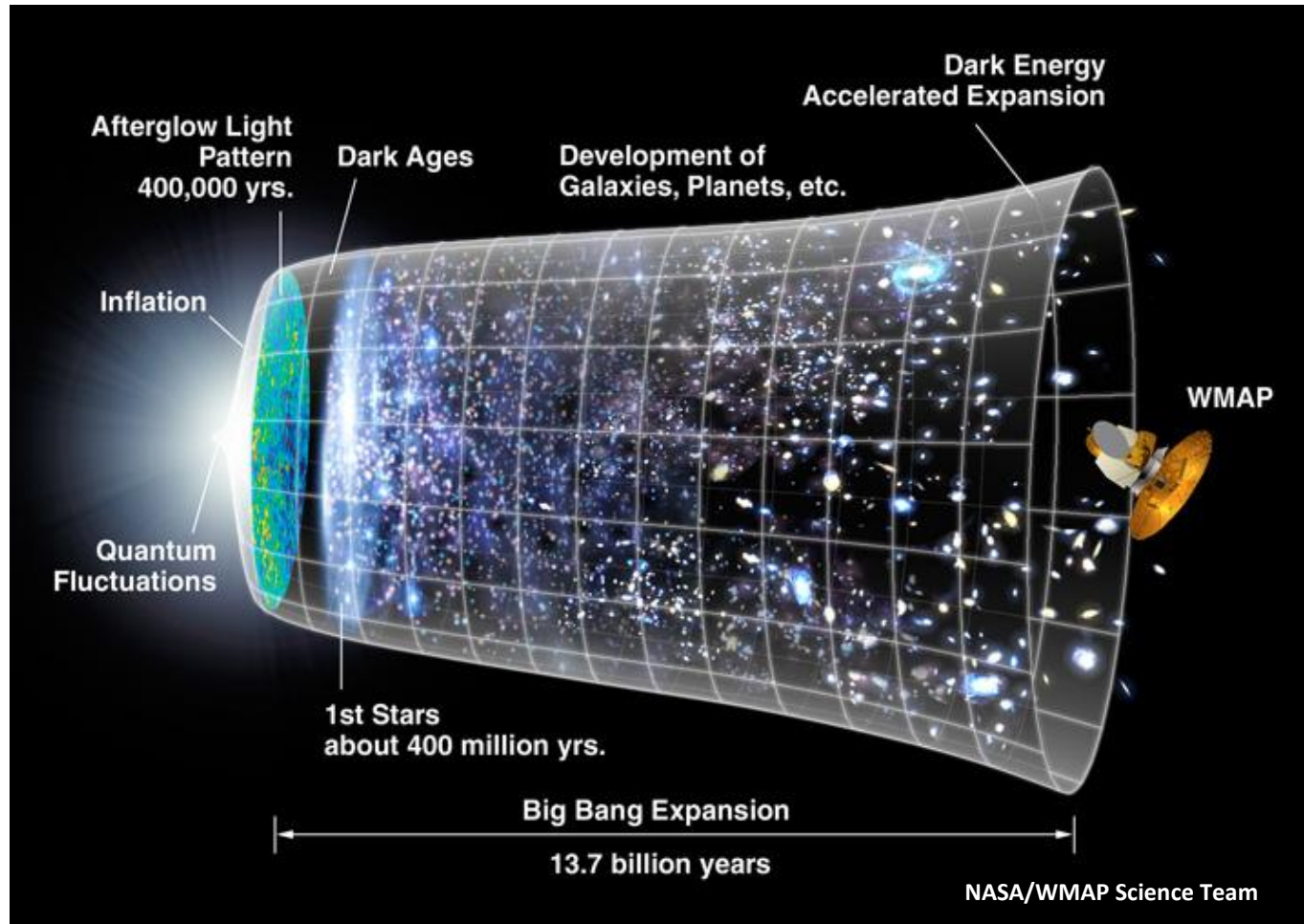
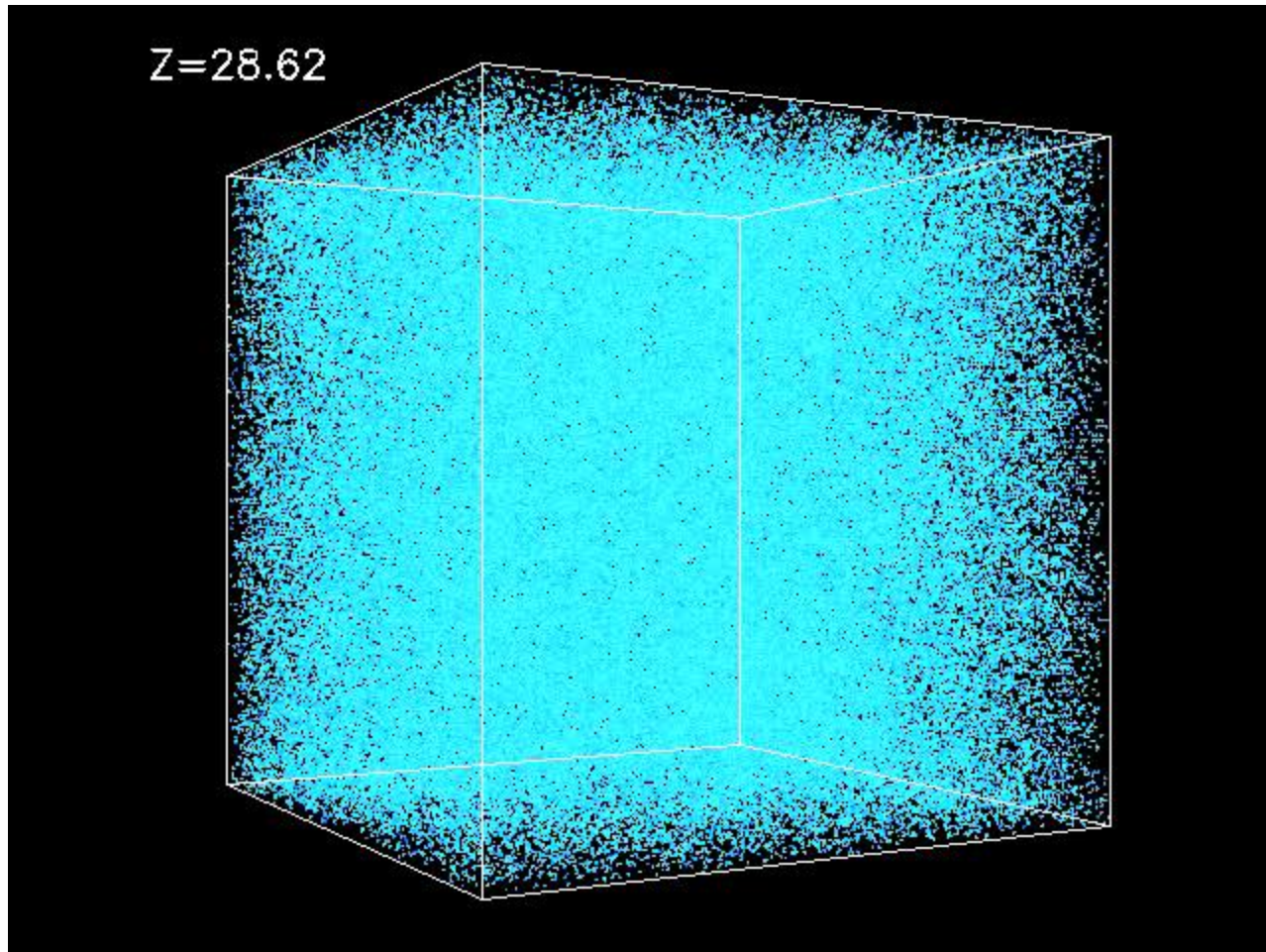# Composition of the Universe

Courtesy: http://hetdex.org
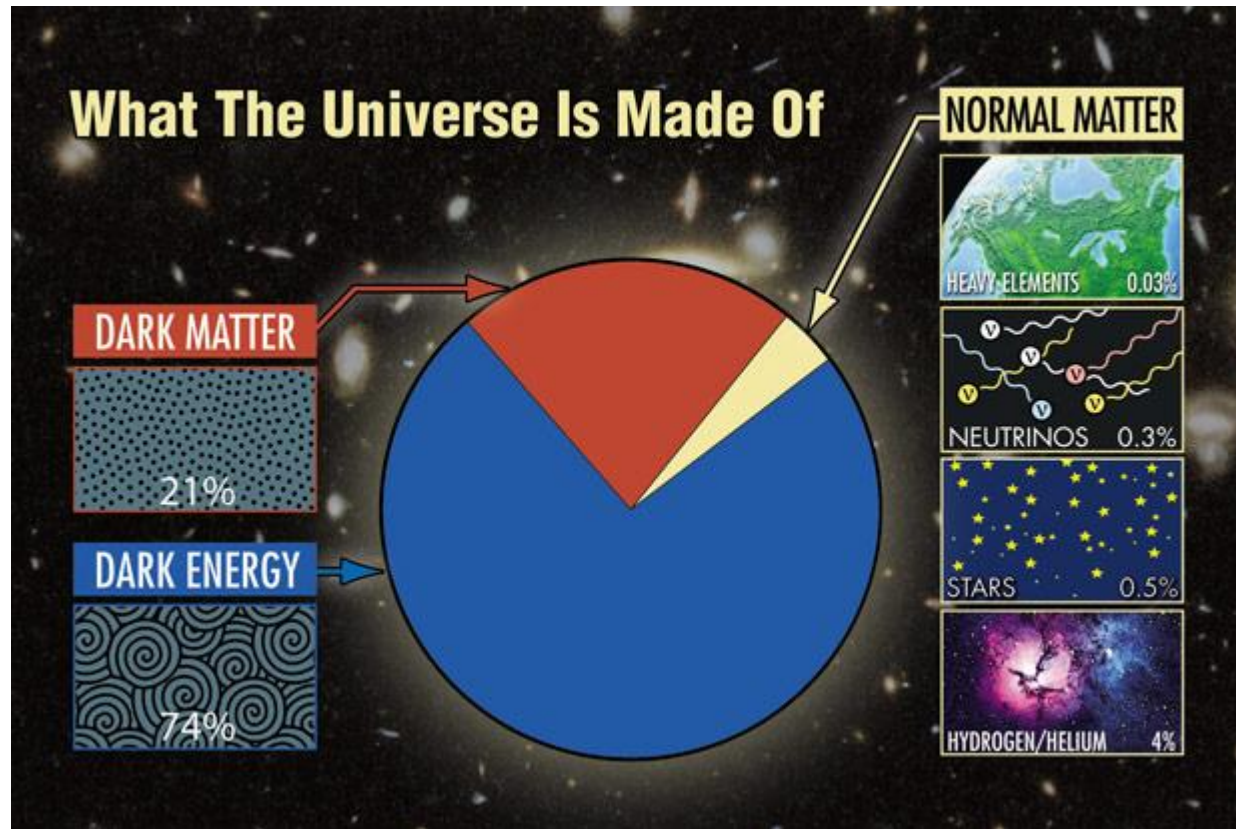
Fundamental Motivation

Discovering the evolution & ultimate fate of the Universe and determining what constitutes 95% of the Universe!

Dark Matter Dominates Galaxy Cluster Formation

Courtesy: http://w3.iihe.ac.be/icecube

Credit: Andrey Kravtsov

Cosmological Mystery

Observations show matter comprises only 25% of the Universe

What makes up the other 75%?

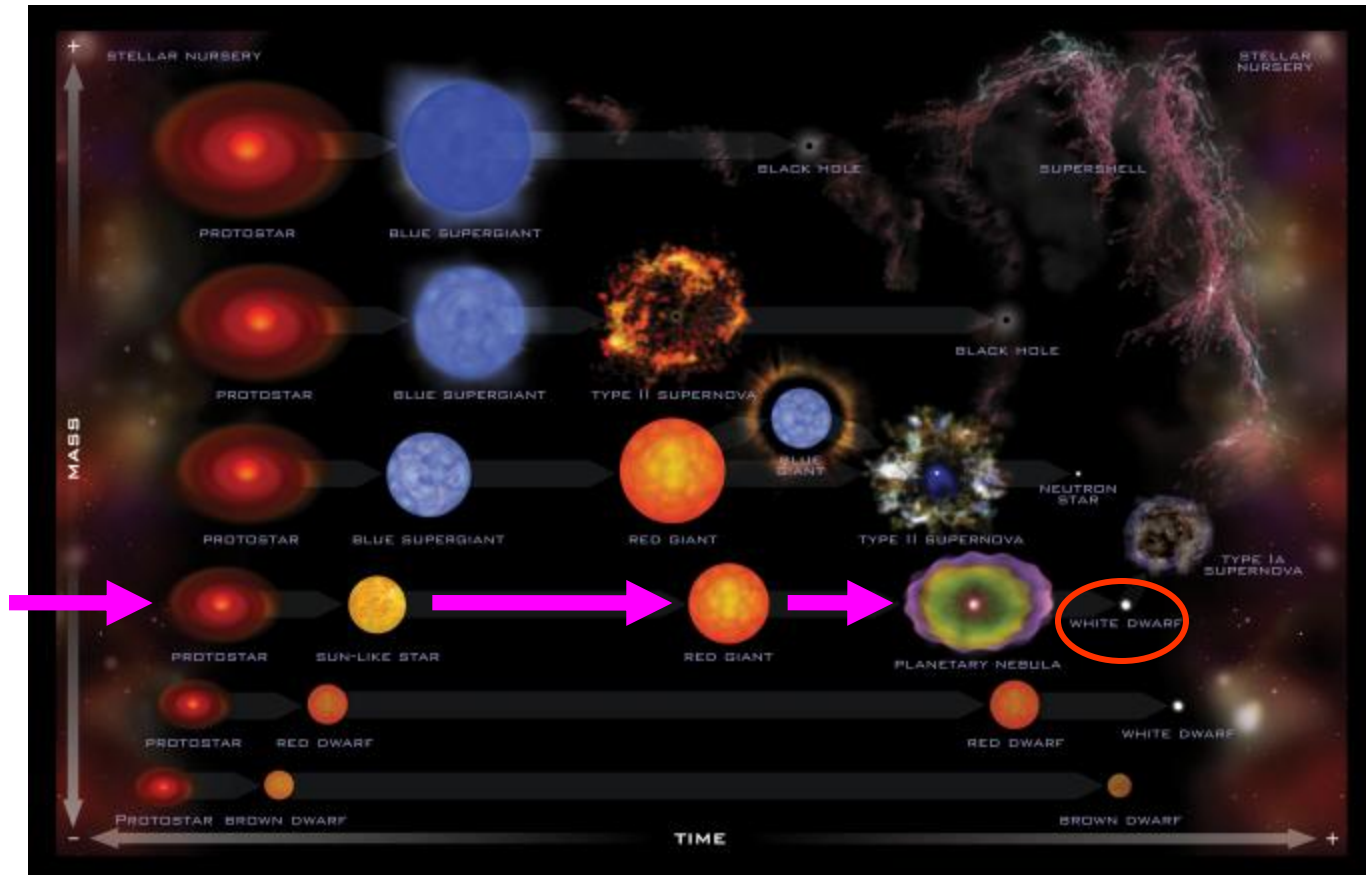# Towards An Answer: Evolution of a Sun-like Star

Image courtesy http://www.siprep.org/faculty/aokeefe

Towards An Answer: Thermonuclear Supernova Animation

Credit: European Southern Observatory
Source: http://www.eso.org/public/videos/eso0943b

BRIGHT!

The galaxy known as NCG 4526 is about 55 million light years away from Earth.

This means that the light from Supernova 1994D started traveling towards Earth ~55 million years before 1994!
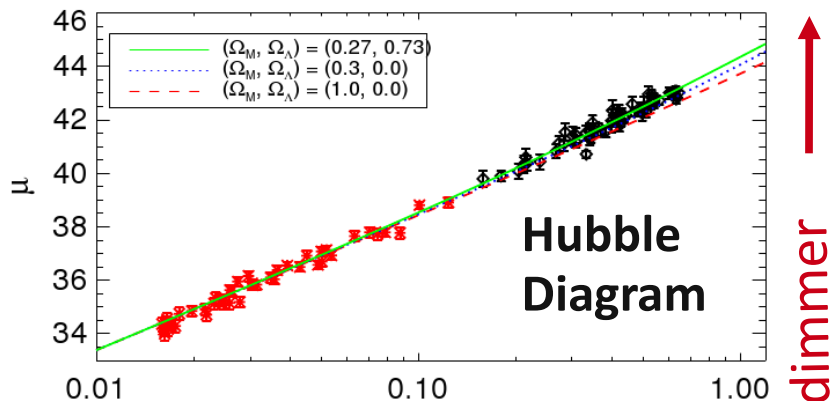

Supernova 1994D in outskirts of galaxy NGC 4526

Credit: High-Z Supernova Search Team, HST, NASA

SNe As Standard Candles

Hubble Diagram

dimmer →
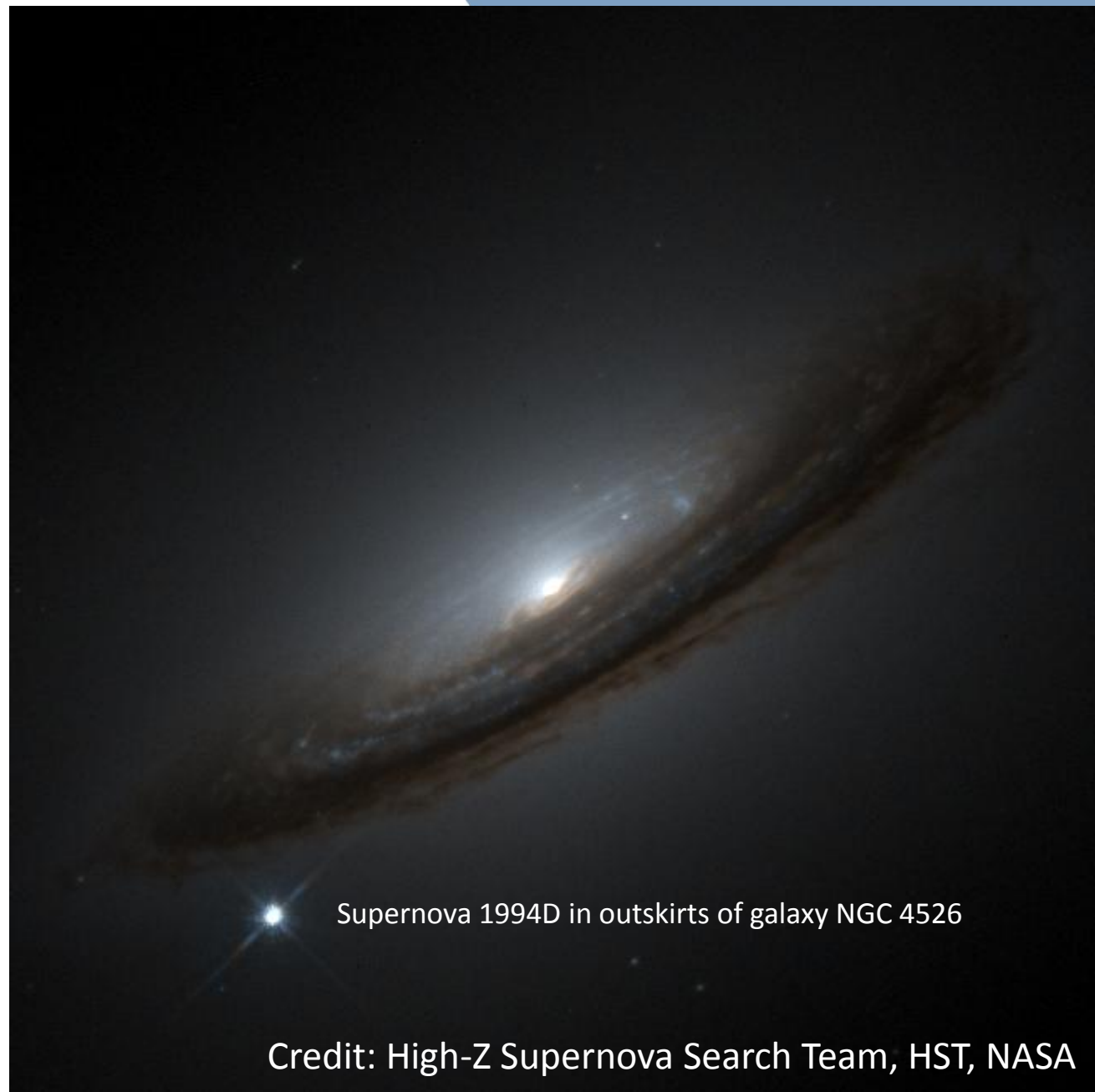
Credit: W. M. Wood-Vasey et al. 2008, ApJ, 666, 694

$1+ z \equiv \lambda_{obs}/\lambda_{emit}$

$z \equiv redshift$

λ_{obs} = observed wavelength

λ_{emit} = emitted wavelength

NB. distance $\propto$ func(z,Ω)

Distance modulus:
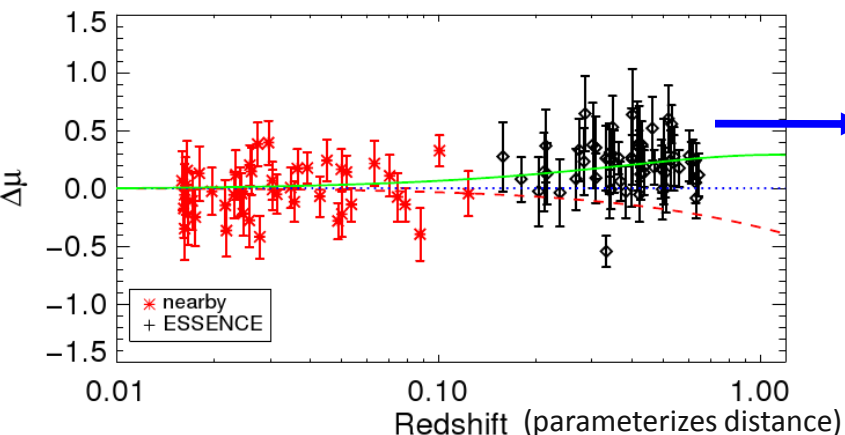
$\mu = 5\log_{10}(d/10 \text{ pc})$

d = distance (1 pc = 3.09×10^{16} m)

Distant SNe dimmer than predicted for a matter-only Universe! (originally discovered in 1998)

Dark Energy: Key to Understanding the Universe

Explanation: expansion of Universe is accelerating due to dark energy that behaves like the opposite of gravity

Just one problem: best model explaining dark energy is off by a factor of 10^{120}
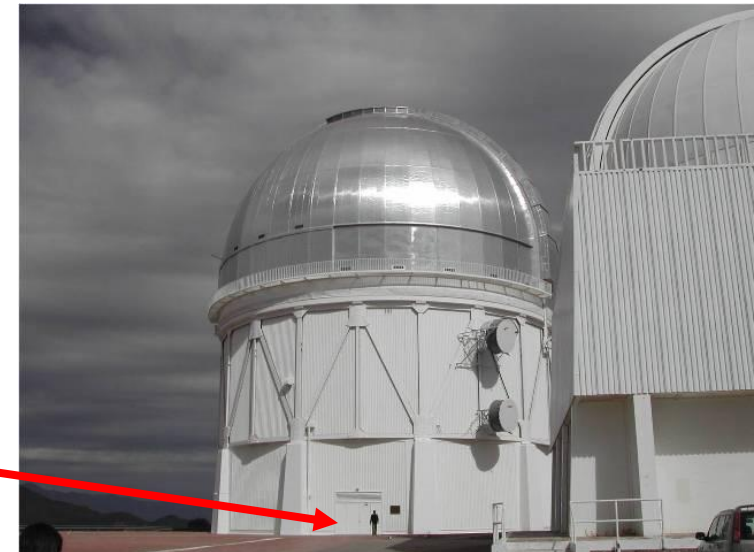
Dark Energy Survey (DES)

DES will survey 5000 square degree of sky and provide new 500Mpixel CCD camera (DECam) for Blanco 4m telescope at the Cerro Tololo Inter-American Observatory (CTIO), Chile, in exchange for 525 survey nights over 5 years starting in 2011.

DE investigation via 4 independent probes:
1) Galaxy angular clustering
2) Weak gravitational lensing
3) Baryon acoustic oscillations
4) SN Ia distances

DES is expected to observe ~10^8 galaxies & will obtain redshifts for the South Pole Telescope survey.
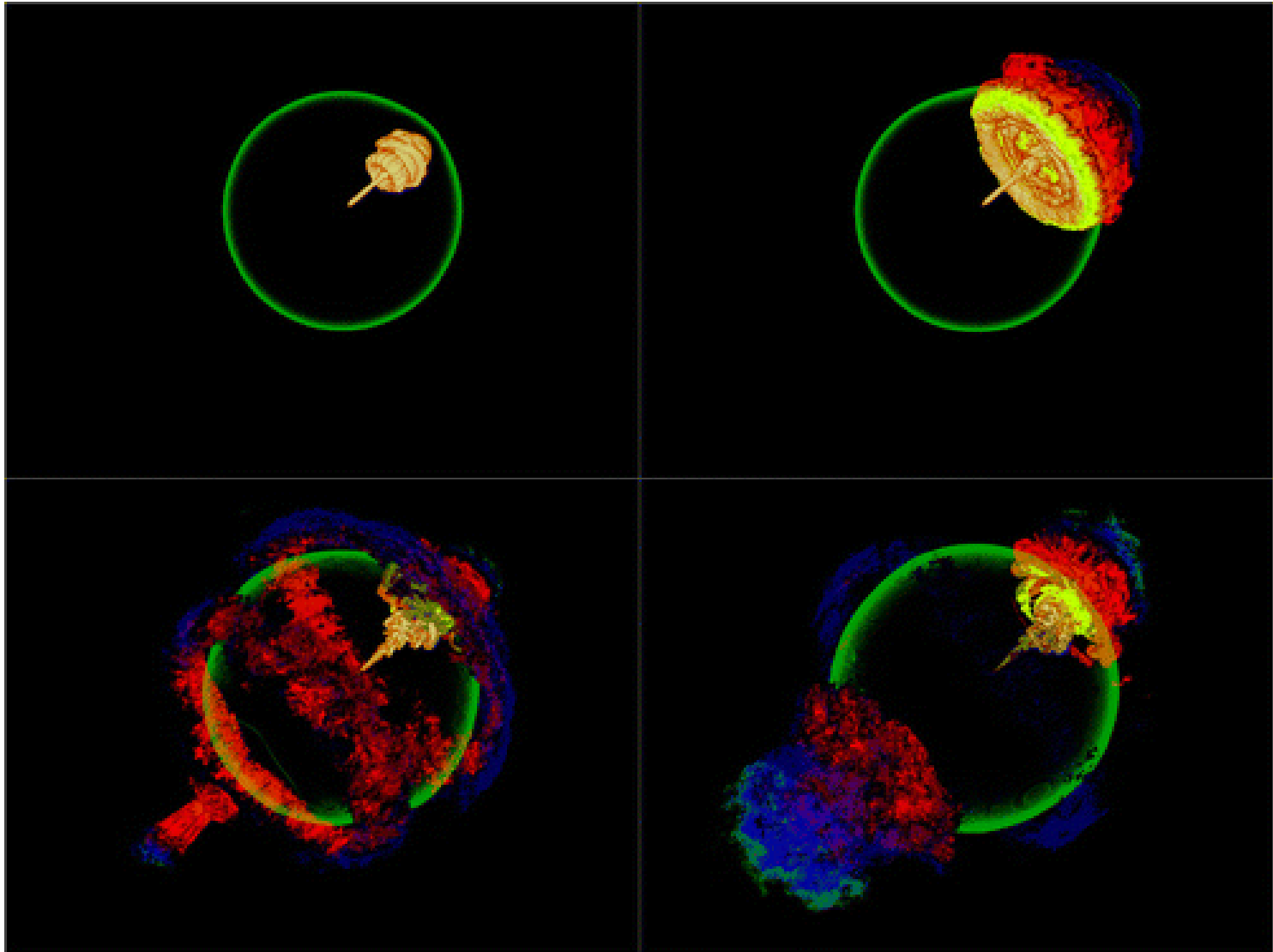
Joe

Pursuing Fundamental Physics with Intrepid

- SN Ia explosion modeling
  - ↗ Argonne – FLASH Center – Others collaboration
  - ↗ simulate white dwarf detonation and explosion using FLASH code
  - ↗ seeking to understand SN Ia brightness from fundamental physics
- SN Ia radiative transfer
  - ↗ PHOENIX
    - ↗ Initial discussions with U. Chicago people have occurred
    - ↗ Argonne FY 2011 LDRD for non-LTE library development pending
    - ↗ Initial BG/P scaling by Daan van Rossum shows promise
  - ↗ SEDONA
    - ↗ Dan Kasen's code (Kasen, Thomas, Nugent 2006, ApJ, 651, 366 (2006)
    - ↗ 2D test runs successfully performed on BG/P
    - ↗ Near ideal scaling for a minimally parallel case
- Computational cosmology
  - ↗ simulate large scale structure of Universe with FLASH
  - ↗ pursuing BG/P optimization & scaling studies w\ Paul Ricker & Boyana Norris
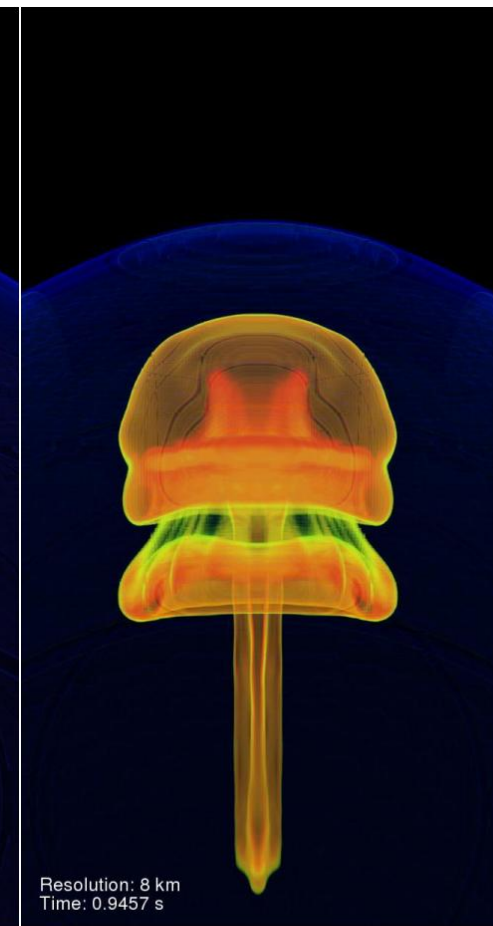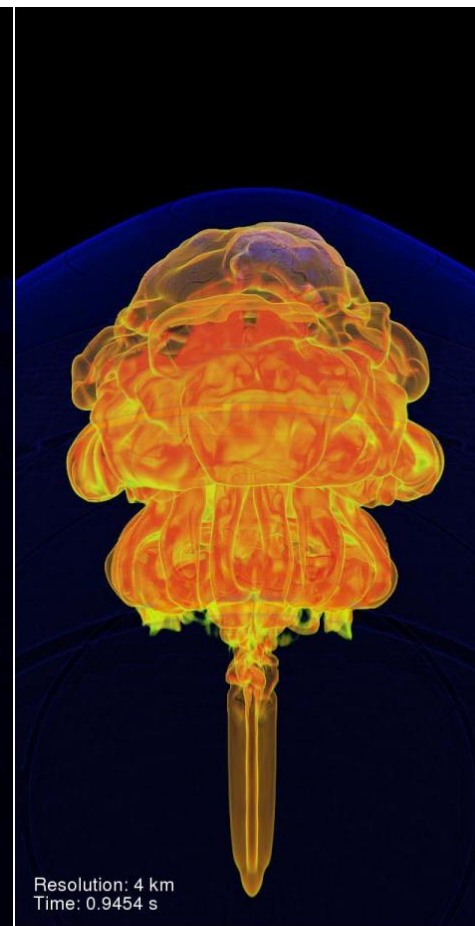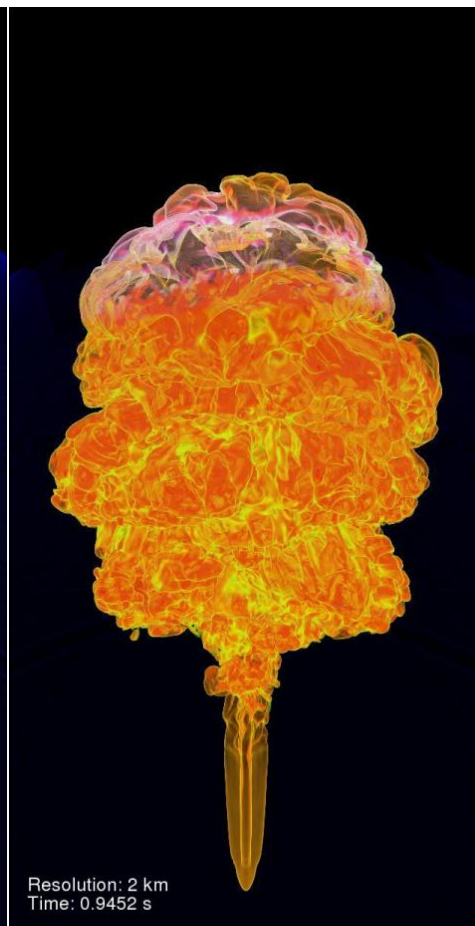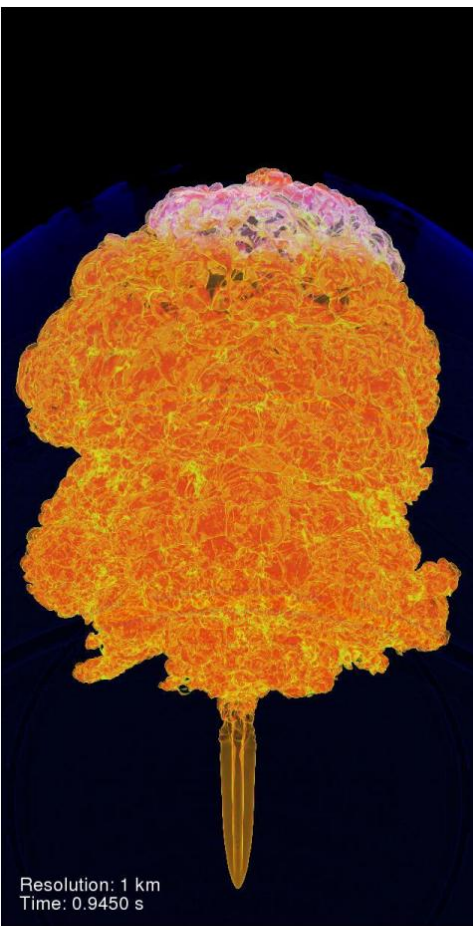
3-D SN Ia Simulations

Jordan et al. 2008, ApJ, 681, 1448

Buoyancy-driven Turbulent Nuclear Combustion

Resolution: 1 km
Time: 0.9450 s

Resolution: 2 km
Time: 0.9452 s

Resolution: 4 km
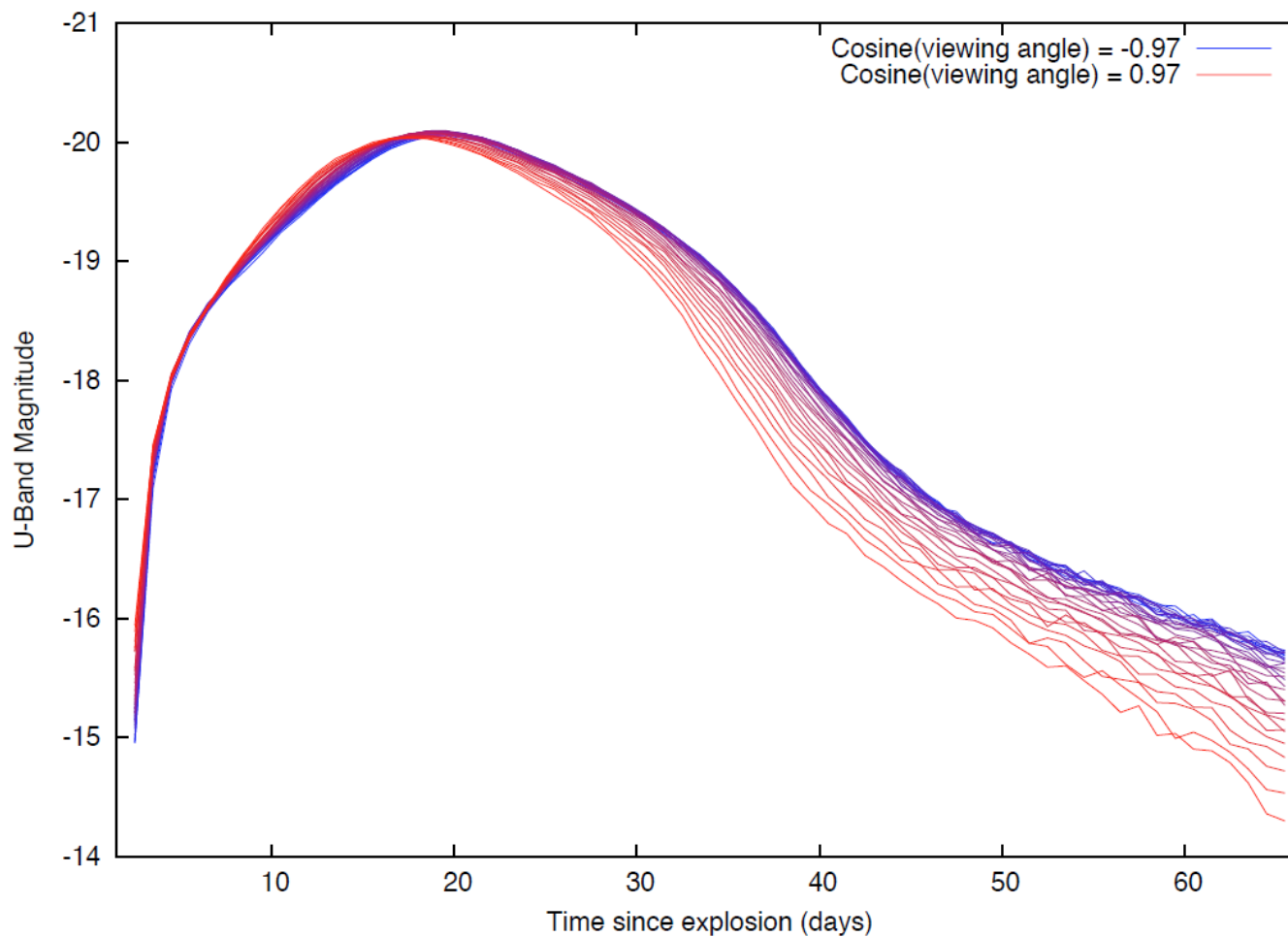Time: 0.9454 s

Resolution: 8 km
Time: 0.9457 s

Credit: Brad Gallagher

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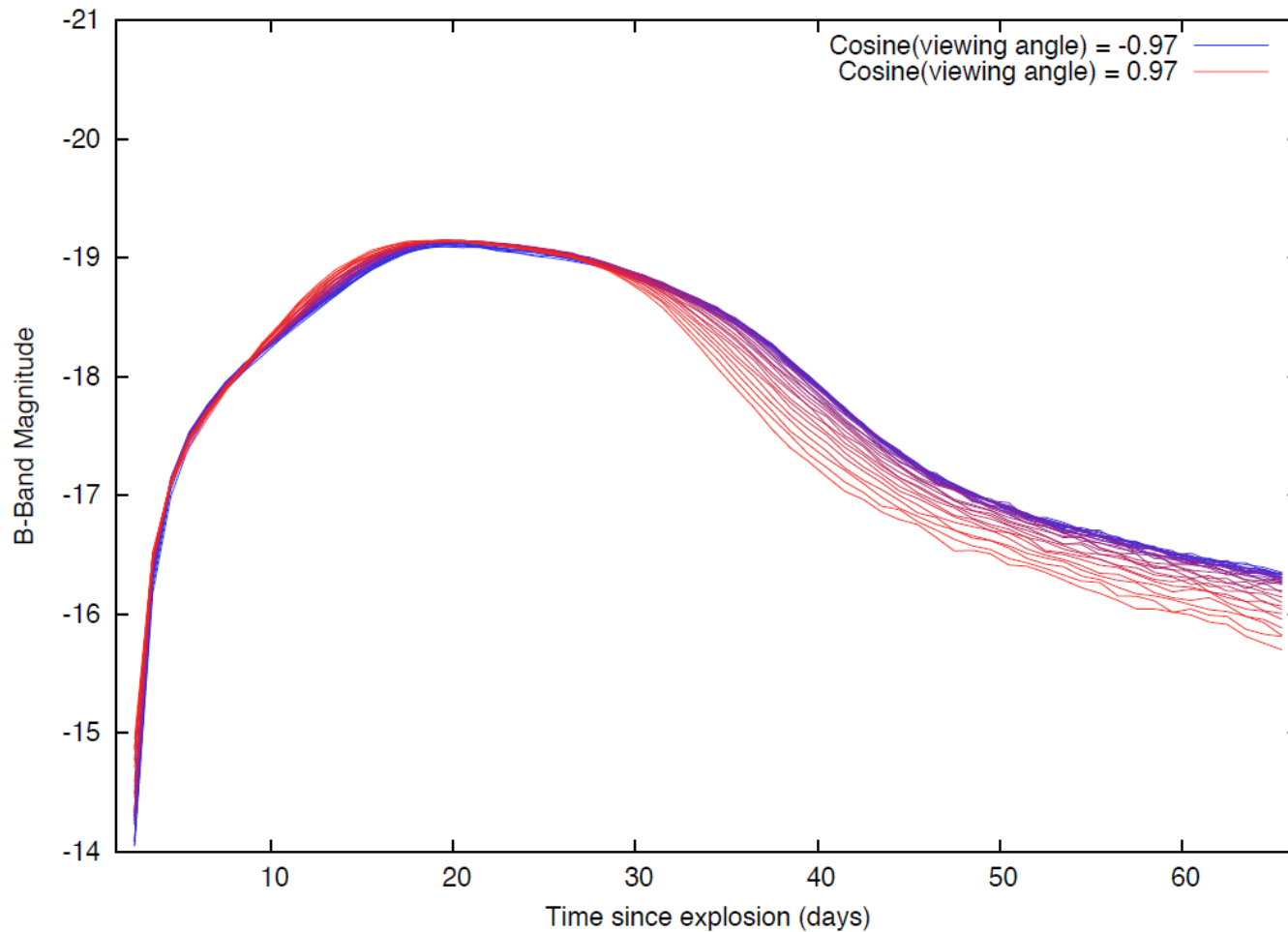
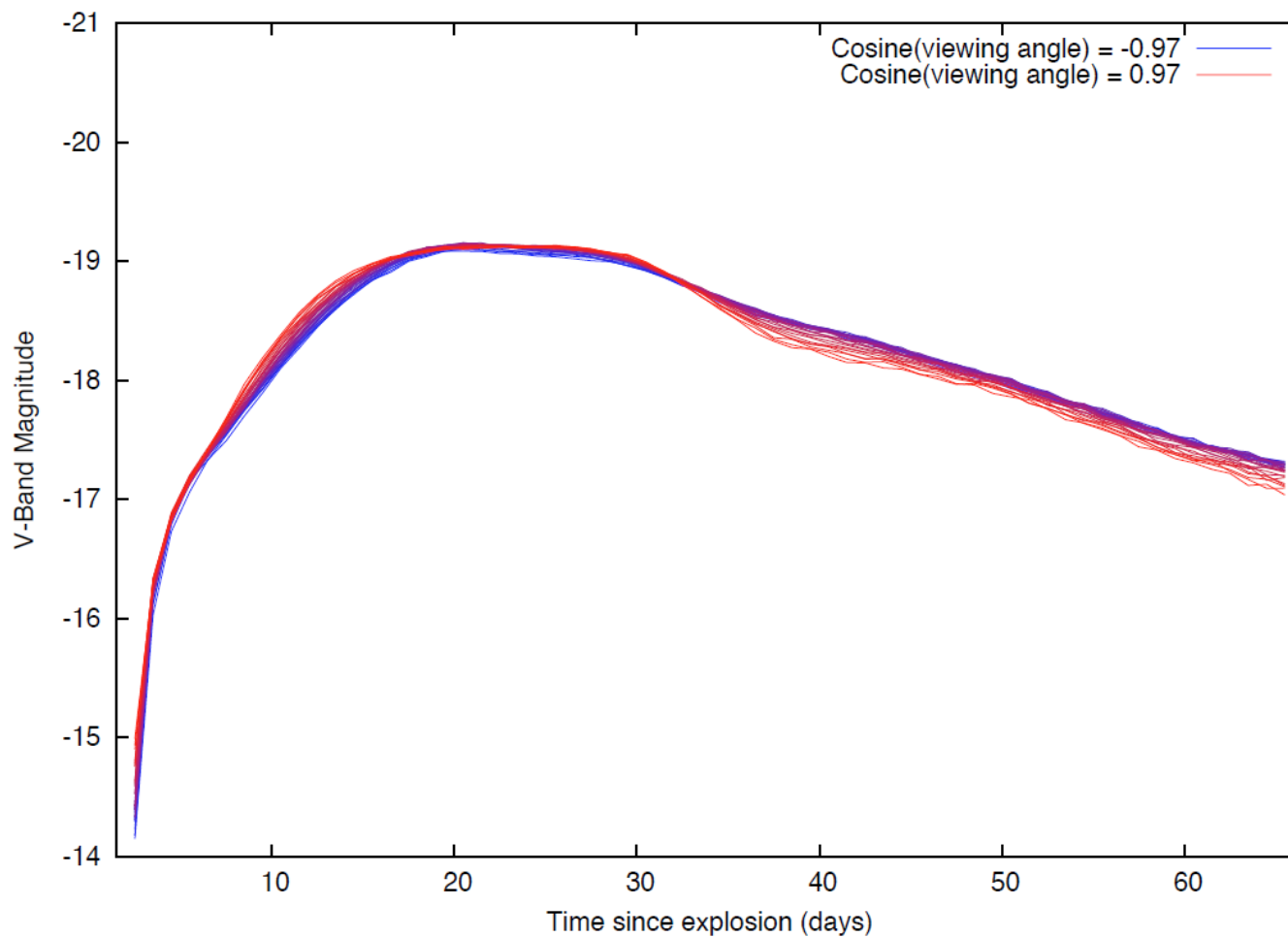# Ultraviolet Brightness vs. Time

Credit: Benedikt Diemer

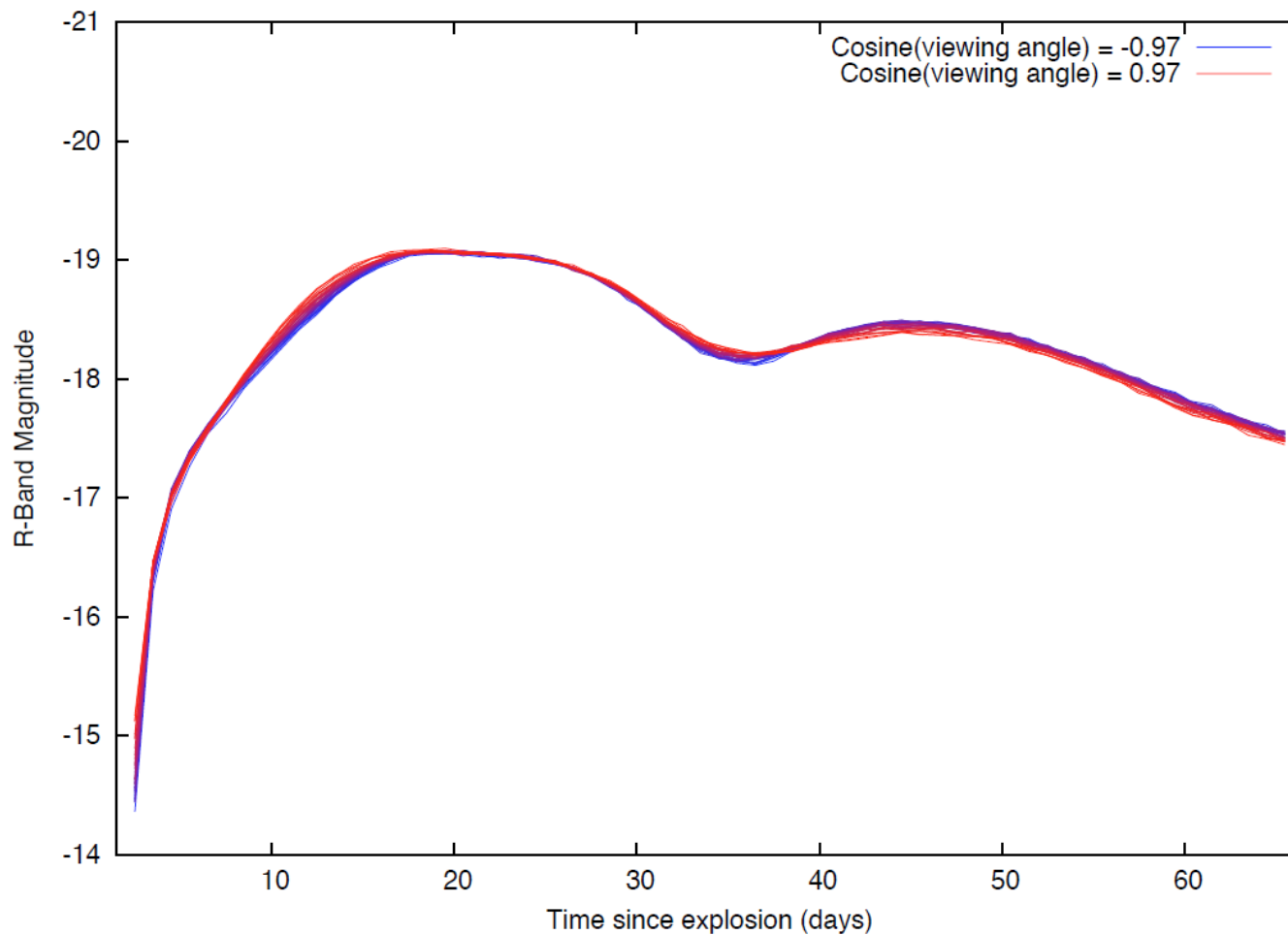# Blue Brightness vs. Time

Credit: Benedikt Diemer

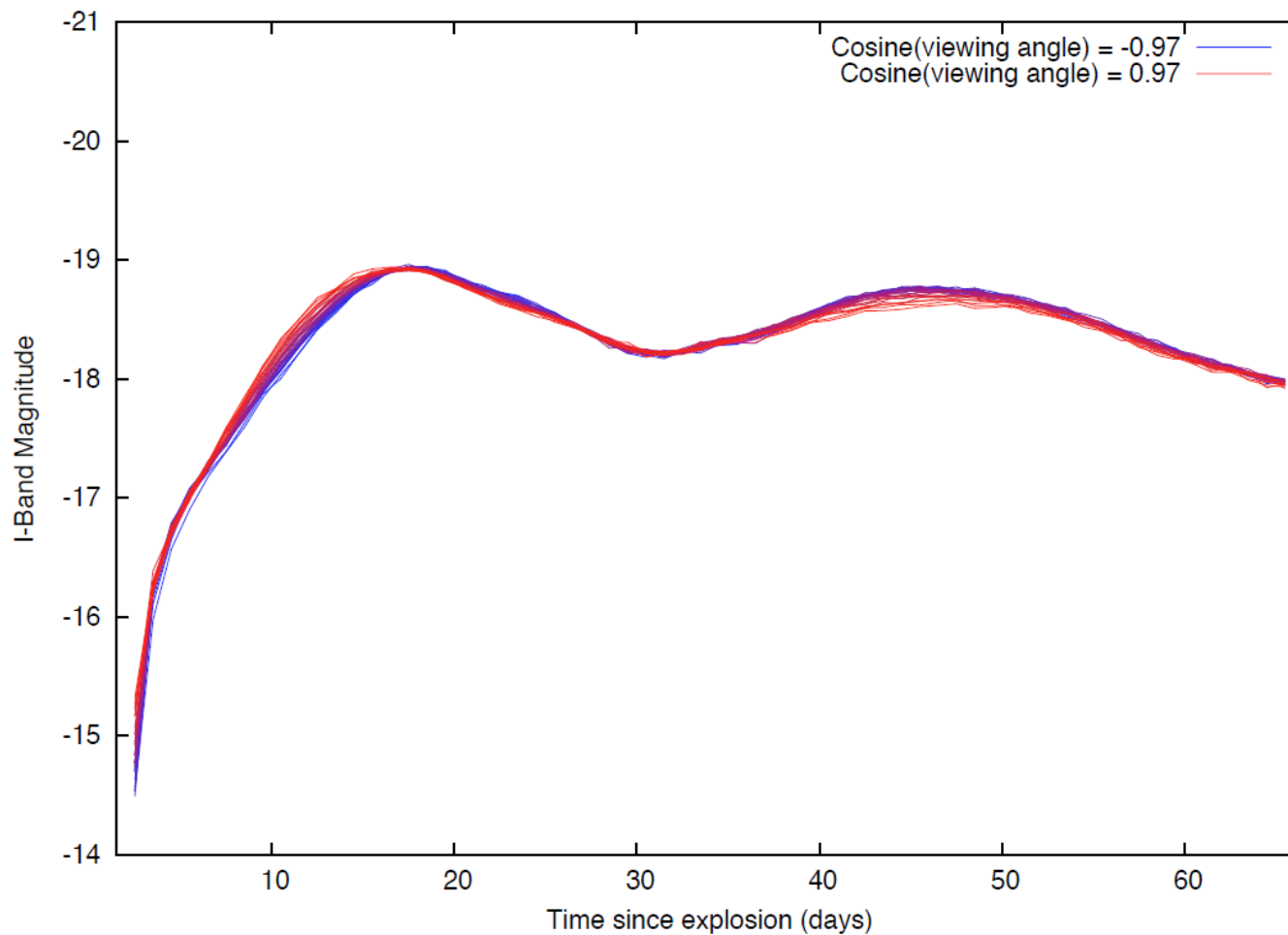# Green Brightness vs. Time
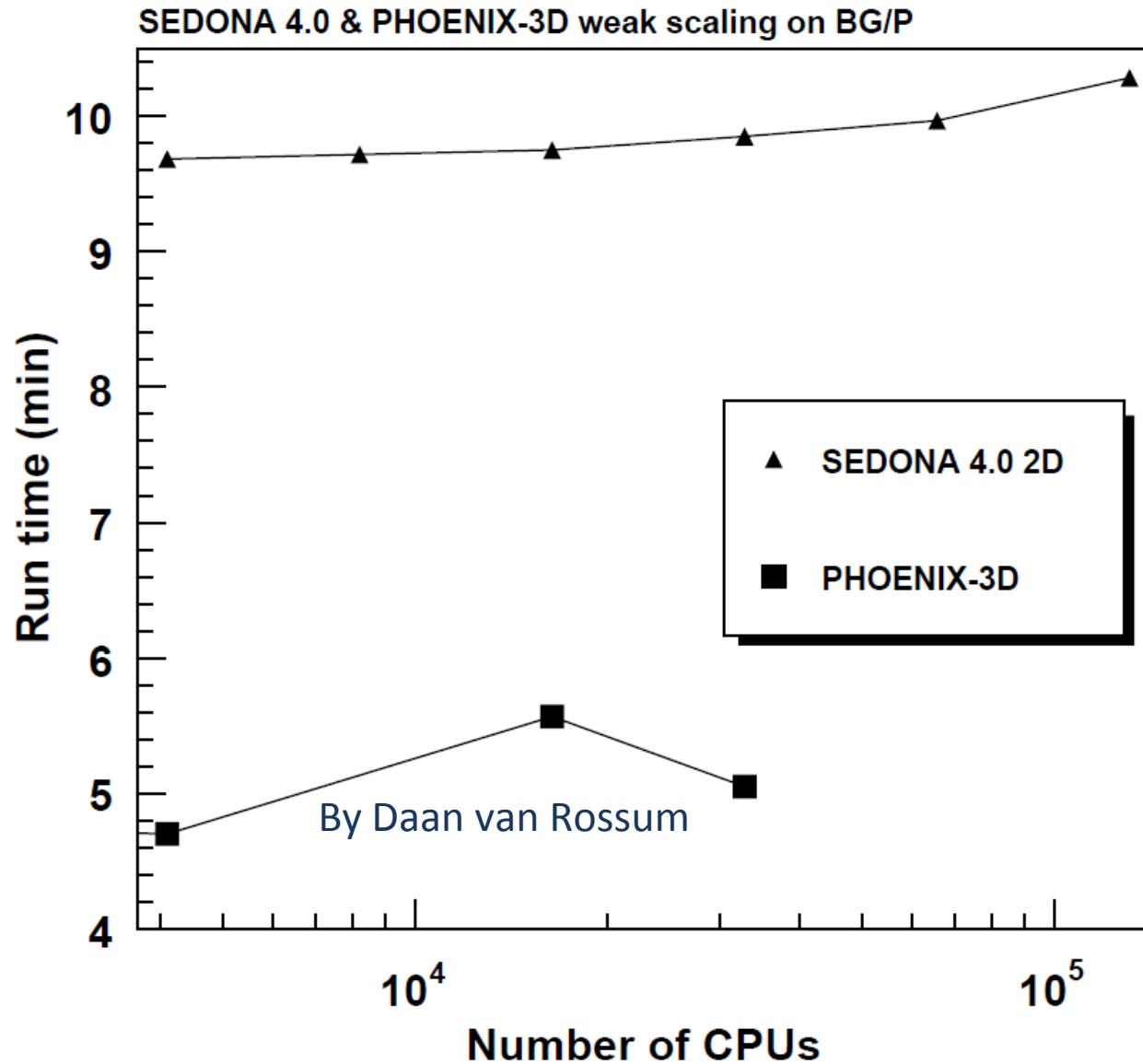

Credit: Benedikt Diemer

Red Brightness vs. Time

Credit: Benedikt Diemer

Infrared Brightness vs. Time

Credit: Benedikt Diemer

Weak Scaling On BG/P (SEDONA: full replication)

SEDONA 4.0 & PHOENIX-3D weak scaling on BG/P

By Daan van Rossum

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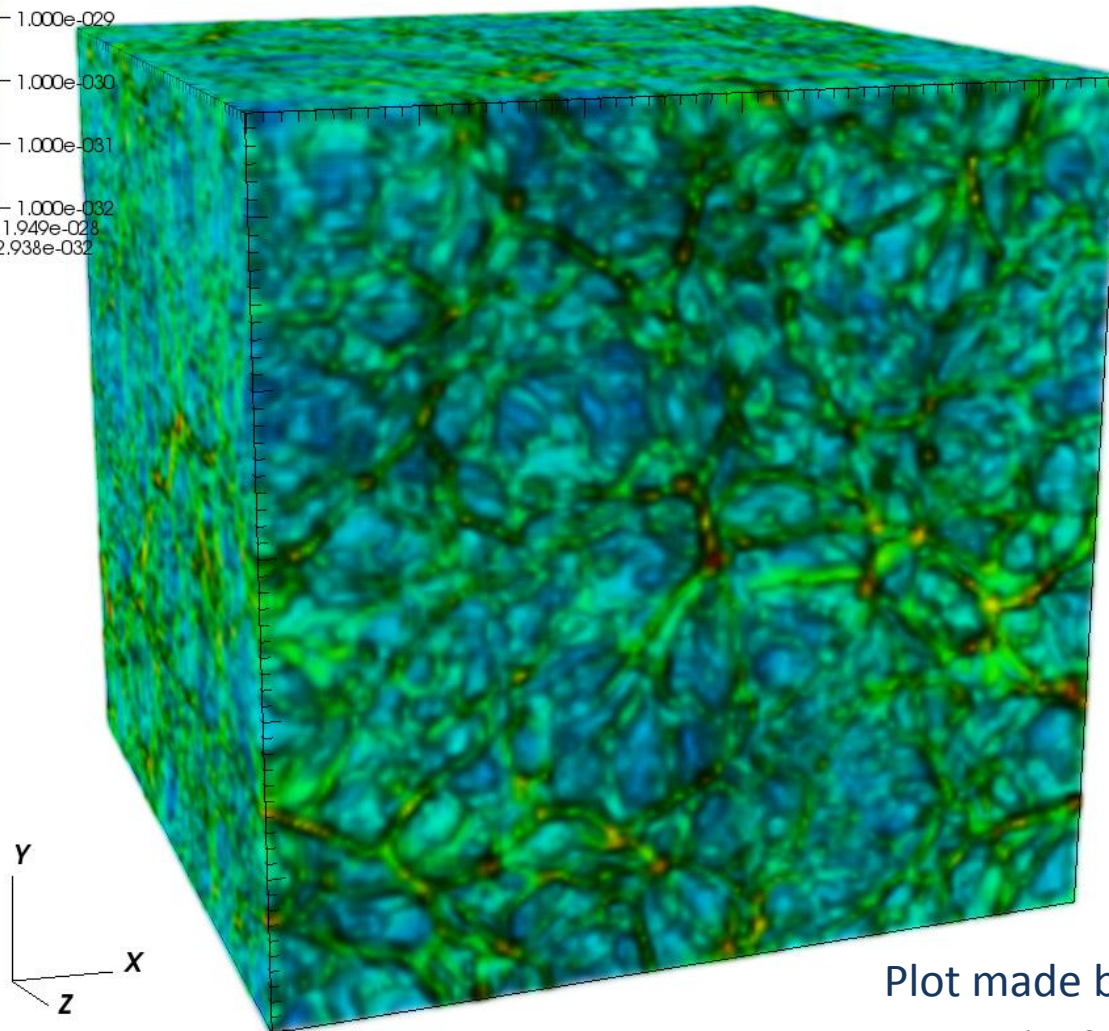
BG/P Test: 512^3 particles w/ hydro (6 refinement levels)
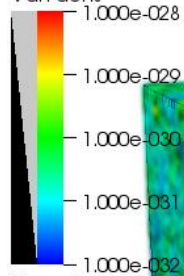
Plot made by Steve Kuhlmann

Active Work

- Radiative transfer : relaxing Local Thermo. Equilibrium (LTE) assumption

    ↗ no existing codes can handle non-LTE assumption at HPC scale

    ↗ Argonne FY 2011 LDRD for non-LTE library development pending (JPB PI)

- Computational cosmology

    ↗ MUCH larger simulations needed

    ↗ working on 1024^3-particle proof of principle problem

    ↗ ultimate technical goal is 4096^3 particles and more

    ↗ science: study voids in Universe – requires extreme force resolution

    ↗ Boyana Norris working on optimization and OpenMP studies

Summary & Conclusion

- Dark energy: one of the most compelling modern physics problems

- March to precision cosmology demands HPC simulations

- ANL actively engaged on two fronts

  - ↗ supernova explosion modeling

  - ↗ computational cosmology

- Many applications suitable to petascale and beyond

- ANL well positioned to maintain leadership roles w/ computational hires